# Status Report on Assembly of Lead-Free Project Test Boards

Joint Group on Pollution Prevention Joint Council on Aging Aircraft

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## **Objective**

 The objective of this presentation is to provide status on the manufacture of the JG-PP/JCAA Joint Test Protocol assemblies and point to future activities.



## **Background**

- Because of the drive in Asia and Europe for "green" electronic products, continued use of tin-lead solder presents business risks, including:
  - concerns about potential environmental legislation banning lead-containing products
  - risk of trade barriers and lost sales
  - reduced mission readiness
  - component obsolescence with lead surface finishes
- The Joint Group on Pollution Prevention began the Lead-Free Solder project in 2001 to have a better understanding of how some promising lead-free solder alloys perform when subjected to typical aerospace environmental conditions.
- JCAA joined JG-PP in May 1, 2003 because they saw the value of the lead-free solder project with regard to the numerous logistical and repair issues.
- Members of the combined team represent military services, NASA (National Aeronautics and Space Administration), various defense, space and commercial contractors, and component and solder suppliers.



## **Background Continued**

- To date, the project participants have:
  - Identified the performance requirements
  - Identified tests for lead-free solders
  - Identified the lead-free solder alternatives that would be tested
  - Completed design of the test circuit card
  - Assembled the 205 board test set and 92 SIR and EMR test boards
  - Assembled 45 Phase II test boards
  - Began reliability testing
- Test set includes similar baseline tin-lead soldered boards.
- The materials were chosen based on initial environmental, safety, and occupational health screening data, as well as previous experience in Japan, Europe and other consortium using lead-free solders.



## **Background Continued**

- The lead-free solder alloys agreed by the project stakeholders to be tested are as follows:
  - Tin-copper (stabilized) (99.3Sn-0.7Cu-0.05Ni) wave and hand soldering
  - Tin-silver-copper (95.5Sn-3.9Ag-0.6Cu) wave, reflow and hand soldering
  - Tin-silver-copper-bismuth (92.3Sn-3.4Ag-1.0Cu-3.3Bi) reflow and hand soldering
- Rockwell Collins designed the test assembly and procured all components.
- BAE Systems Irving, formerly Boeing Commercial Electronics Irving, agreed to assemble the test boards as our part in the consortium activities. Our facility and product were considered typical of factories producing a highly reliable product with enough volume to simulate a higher capacity production run.
- The project will generate critical reliability data on circuit cards manufactured and reworked with lead-free and eutectic tin-lead solders for military and space applications as documented in the Joint Test Protocol.



## **Assembly Details**



## **Test Vehicle- Printed Wiring Assembly**

#### **PWB**

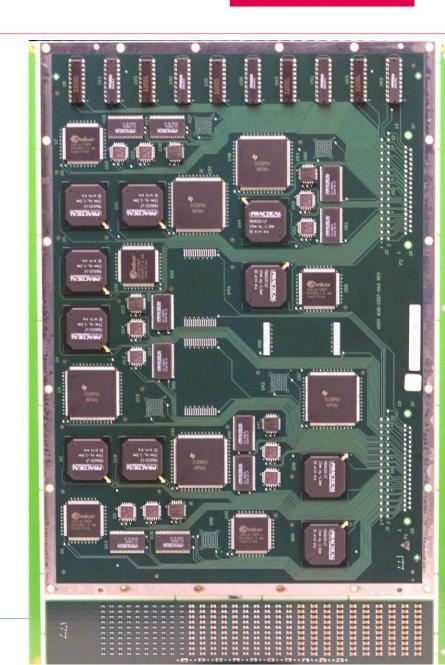
- 14.5"X 9"X 0.09"
- 6 layers
- Immersion Silver (Tg~170°C, GF- Pb-free PWAs)
- SnPb HASL (Tg~140°C, GF- Rework PWAs )

#### **PWA**

- Surface mount and through hole components
- Total Quantity: 205 (119/86)

### Lead-Free Solder Alloys

- Sn3.9Ag0.6Cu (SnAgCu)
- Sn3.4Ag1.0Cu3.3Bi (SnAgCuBi)
- Sn0.7Cu (SnCu)





## **Materials**

Material	Wave Soldering	Reflow Soldering	Hand Soldering
Sn0.7Cu (stabilized)	X	N/A	Flux Cored Solder RMA (NoClean)
Flux	VOC Free No Clean Flux	N/A	R Heat Stabilized Resin ROL0 Tacky Flux
Sn3.9Ag0.6Cu	Sn3.5Ag.7Cu	X	Flux Cored Solder RMA
Flux	VOC Free No Clean Flux	ROL1	R Heat Stabilized Resin ROL0 Tacky Flux
Sn3.4Ag1Cu3.3Bi	N/A	Sn3.35Ag1Cu3.3Bi	0.010 Dia. Wire
Flux	N/A	No Clean (RMA)	R Heat Stabilized Resin ROL0 Tacky Flux
Sn37Pb	X	X	Flux Cored Solder RMA
Flux Type ORM0		ROL0	ORL0 ROL0 Tacky Flux

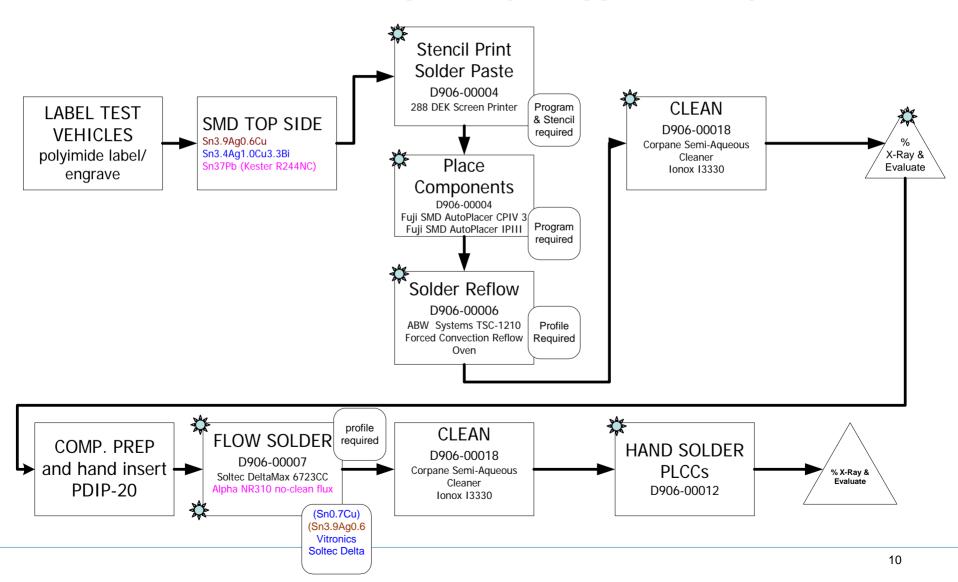


## Components

Component Type	Component Finish		
	SnPb		
CLCC-20	SnAgCu		
	SnAgCuBi		
PLCC-20	Sn		
TSOP-50	SnPb		
	SnCu		
TQFP-144	Sn		
TQFP-208	NiPdAu		
BGA-225	SnPb		
	SnAgCu		
DIP-20	Sn		
	NiPdAu		
0402Cap	Sn		
0805Cap	Sn		
1206Cap	Sn		
1206Res	Sn		



#### LEAD-FREE TEST VEHICLE ASSEMBLY FLOW





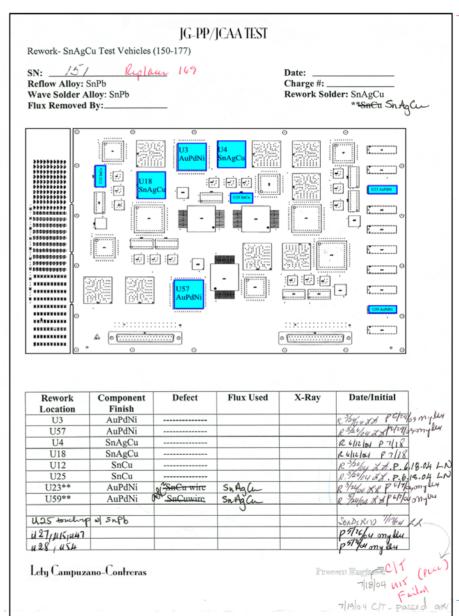
## **Assembly Notes**

- All PLCCs were hand soldered with either SnPb, SnAgCu, or SnAgCuBi solder.
- Lead-Free wave solder with SnCu and SnAgCu was performed at Vitronics-Soltec in New Hampshire.
- After wave solder at Vitronics, the assemblies were cleaned at Kyzen in New Hampshire.



#### **Production Environment**

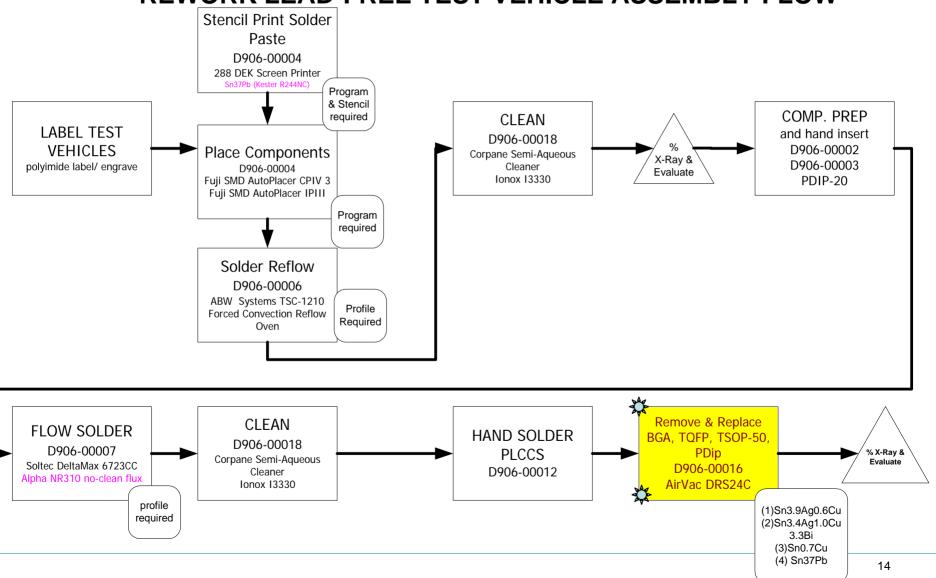
- Simulate production environment
- •Full compliance to standard process control documents
- Formal planning sequence (CAAP)
- Certified operators and inspectors
- •PE/QE special training for factory personnel
- Traveler used for serial number documentation





## Rework

### REWORK LEAD-FREE TEST VEHICLE ASSEMBLY FLOW





#### **Rework Assemblies**

Selected pairs of the following component types were removed and replaced to look at the effects on the assembly due to the additional and higher temperature and/or different solder joint metallurgy: BGA, TQFP-208, TSOP-50, DIP





## Rework *Control* Boards (SnPb solder initially; reworked with SnPb solder)

Location	Part Number	Qty Per Board	Part Finish Before Rework	Replacement Part Finish
U25	TSOP-50	1	SnPb	SnPb
U12	TSOP-50	1	SnPb	SnPb
U57	TQFP-208	1	NiPdAu	NiPdAu
U3	TQFP-208	1	NiPdAu	NiPdAu
U18	BGA-225	1	SnPb	SnPb
U4	BGA-225	1	SnPb	SnPb
U59	DIP-20	1	NiPdAu	NiPdAu
U23	DIP-20	1	NiPdAu	NiPdAu



## Rework Boards (SnPb solder initially; reworked with SnAgCu or SnAgCuBi solder)

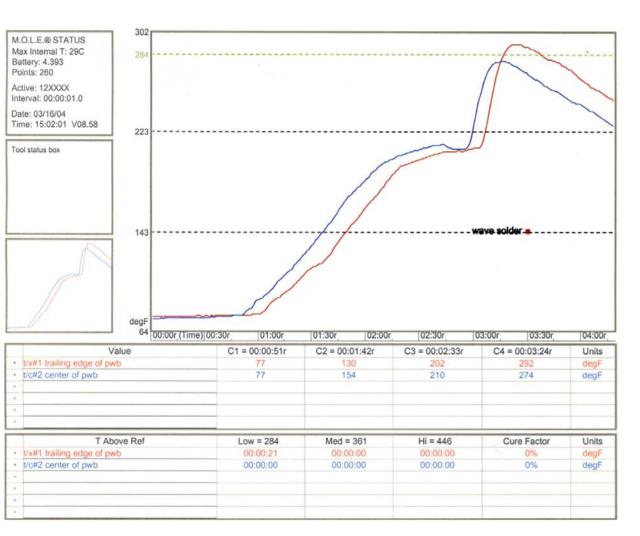
Location	Part Number	Qty Per Board	Part Finish Before Rework	Replacement Part Finish
U25	TSOP-50	1	SnPb	SnCu
U12	TSOP-50	1	SnPb	SnCu
U57	TQFP-208	1	NiPdAu	NiPdAu
U3	TQFP-208	1	NiPdAu	NiPdAu
U18	BGA-225	1	SnPb	SnAgCu
U4	BGA-225	1	SnPb	SnAgCu
U59	DIP-20	1	NiPdAu	NiPdAu
U23	DIP-20	1	NiPdAu	NiPdAu



## Tin Lead Solder (SnPb)



## Wave Solder SnPb Profile (Rework & Manufactured-Control)

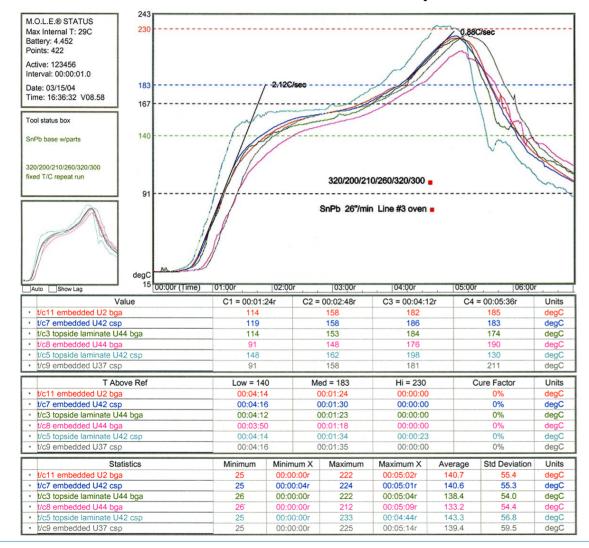


Typical SnPb Profile

Solder Pot Temperature = 250°C Preheat Board T = 101°C Peak Temperature = 144°C Speed: 110 cm/min



## Reflow Oven SnPb Solder Profile (Rework & Manufactured-Control)

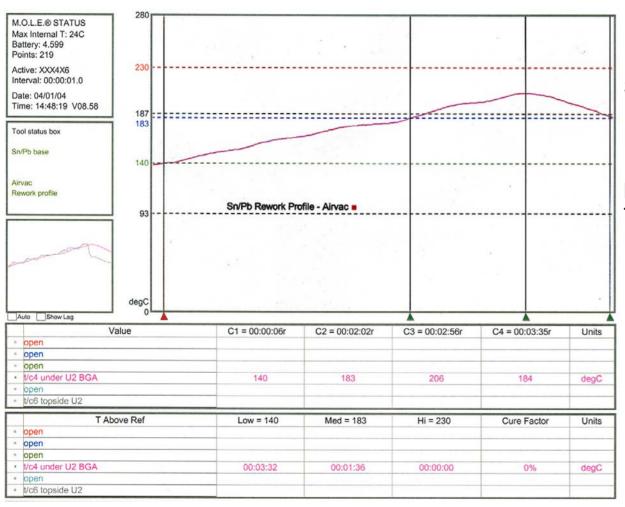


Standard SnPb Profile

Preheat = ~ 120 seconds @140-183°C Peak temperature = 225°C Time above reflow = 60-90 sec Ramp Rate = 2-3 °C/sec



## AIR-VAC DRS24C.2D SnPb Rework Profile for BGA Removal & Replacement



Standard SnPb Rework Profile

Preheat = ~ 120 seconds @140-183°C

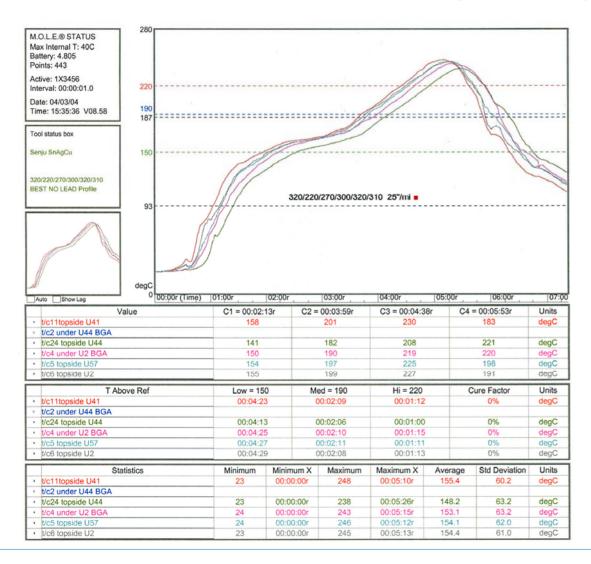
Ball Peak temperature = 206°C Time above reflow = 96 seconds Ramp Rate = 2-3 °C/sec



Tin-Silver-Copper (SnAgCu) and Tin-Silver-Copper-Bismuth (SnAgCuBi)



## Reflow Oven Lead-Free Solder (SnAgCu & SnAgCuBi) Profile



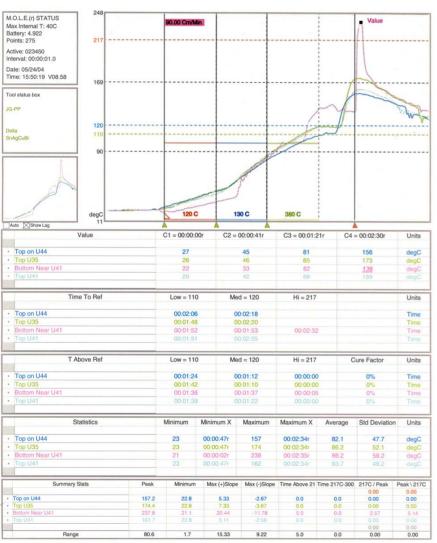
Based on consortium agreed requirements:

Preheat = 60-120 seconds @150-190°C

Peak temperature target = 243°C Reflow:

- ~20 seconds above 230°C
- ~30-90 seconds above 220°C

### **Lead-Free Solder Wave Solder Profile**



Solder Pot Temperature = 265°C for SnCu

Preheat Board T = 134°C

Peak Temperature = 157°C

Speed: 90 cm/min

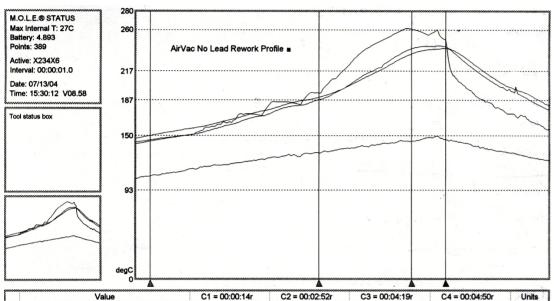
Solder Pot Temperature = 260°C for SnAgCu Preheat Board T = 136°C Peak Temperature = 161°C

Speed: 90 cm/min

Profile provided by Vitronics-Soltec



### AIR-VAC DRS24C.2D Lead-Free Rework Profile for BGA Replacement



Value	C1 = 00:00:14r	C2 = 00:02:52r	C3 = 00:04:19r	C4 = 00:04:50r	Units
□ open			90, 10	8	
■ t/c2 top of U2 body	146	194	261	249	degC
□ board surface	108	132	144	146	degC
■ t/c4 under U2 BGA in pad	150	190	235	241	degC
□ open					
■ t/c6 topside under U2	144	187	241	242	degC

T Above Ref	Low = 150	Med = 217	Hi = 260	Cure Factor	Units
open open					
■ t/c2 top of U2 body	00:05:44	00:01:41	00:00:14	0%	degC
board surface	00:00:00	00:00:00	00:00:00	0%	degC
t/c4 under U2 BGA in pad	00:06;14	00:01:37	00:00:00	0%	degC
□ open					
t/c6 topside under U2	00:05:43	00:01:36	00:00:00	0%	degC

r	Statistics	Minimum	Minimum X	Maximum	Maximum X	Average	Std Deviation	Units
0	open			67			1	
	t/c2 top of U2 body	143	00:00:00r	262	00:04:13r	192.7	37.1	degC
	board surface	105	00:00:00r	149	00:04:41r	129.9	<b>11.7</b>	degC
	t/c4 under U2 BGA in pad	147	00:00:00r	241	00:04:46r	193.3	28.4	degC
0	open	,	áð.					
8	t/c6 topside under U2	141	00:00:00r	243	00:04:41r	190.9	31.4	degC

Device joint target = 243°C

Device top max target = 260°C

Board target = 110°C (process starting point)

Board max = 150°C

Reflow:

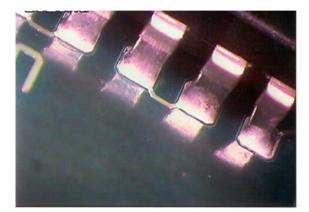
- ~97 seconds above 217°C
- ~75 seconds above 221°C
- ~44 seconds above 235°C Ball temperature 241°C Ramp rate 1.14°C/sec



## Results



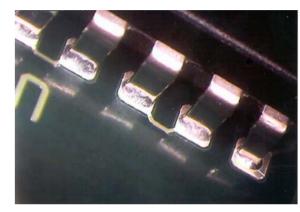
## Comparison of NiPdAu DIPs wave soldered with SnPb, SnCu, or SnAgCu



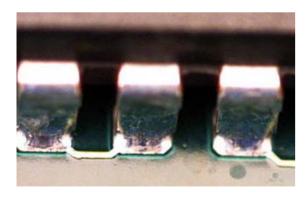
SN10: U35 with SnPb



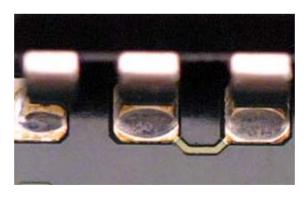
SN121: U35 with SnCu



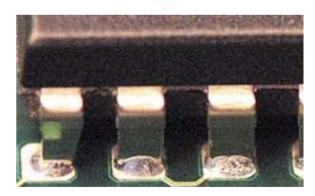
SN80: U35 with SnAgCu



SN41: U59 with SnPb



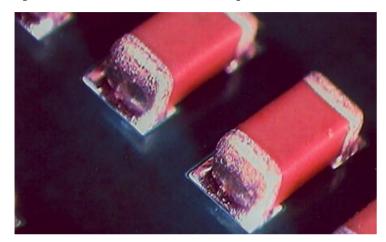
SN138:U59 with SnCu



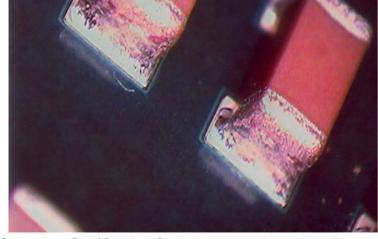
SN110: U59 with SnAgCu



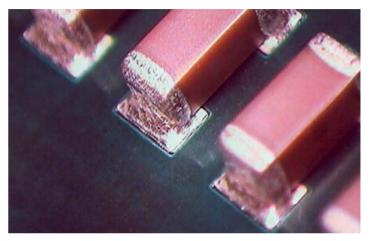
## Comparison of 0805 Capacitors soldered with SnPb, SnAgCu and SnAgCuBi



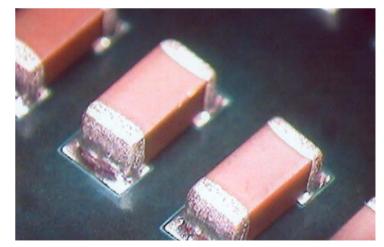
SN40 Sn/SnPb, Immersion Ag PWB



SN105 Sn/SnAgCu, Immersion Ag PWB



SN137 Sn/SnAgCuBi, Immersion Ag PWB



SN34 SnPb/SnPb, SnPb HASL PWB



## Comparison of TQFP-208 replaced with SnPb, SnAgCu and SnAgCuBi







SN44 U57 reworked with SnPb SN177 reworked with SnAgCu

SN205 reworked with SnAgCuBi

SnPb HASL PWB



## Comparison of different surface finish CLCCs soldered with SnPb, SnAgCu, and SnAgCuBi



BOEING



SN44 U17 SnPb lead surface finish soldered with SnPb

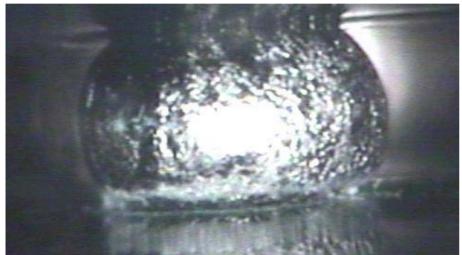
SN156 U17 SnAgCu lead surface finish soldered with SnPb

SN182 U17 SnAgCuBi lead surface finish soldered with SnPb

SnPb HASL PWB



## Comparison of SnAgCu BGA and SnPb BGA soldered with SnAgCu.



SN110 U56 SnPb soldered with SnAgCu Immersion Ag PWB Lead-Free Reflow Profile



SN110 U55 SnAgCu soldered with SnAgCu Immersion Ag PWB Lead-Free Reflow Profile



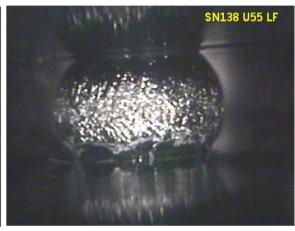
## Comparison of SnAgCu BGA soldered with SnPb, SnAgCu, and SnAgCuBi



SN205 U56 (SnAgCu) SnPb solder SnPb HASL PWB SnPb Reflow Profile



SN110 U55 (SnAgCu) SnAgCu solder Immersion Ag PWB Lead-Free Reflow Profile



SN138 U55 (SnAgCu) SnAgCuBi solder Immersion Ag PWB Lead-Free Reflow Profile



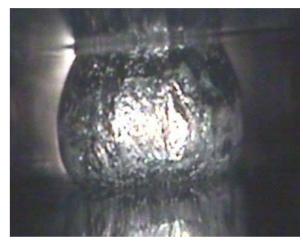
## Comparison of SnPb BGAs soldered with SnPb, SnAgCu and SnAgCuBi



SN44 U56 soldered with SnPb.



SN110 U56 soldered with SnAgCu.



SN138 U56 soldered with SnAgCuBi.



## Comparison of BGAs soldered with SnPb Solder and reflow profile



SN44 SnPb Rework-Control SnPb BGA: SnPb solder



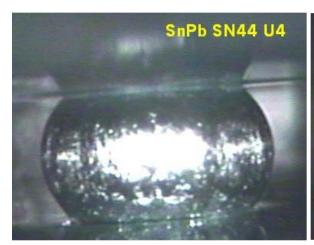
SN177 SnAgCu Rework SnAgCu BGA: SnPb solder



SN205 SnAgCuBi Rework SnAgCu BGA: SnPb solder



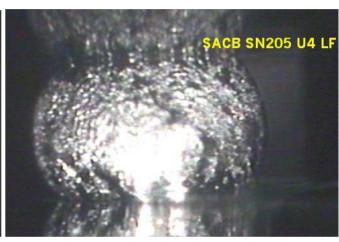
## **Comparison of reworked BGAs**



SN44 U4 SnPb BGA reflowed



SN177 U4 SnAgCu BGA reflowed



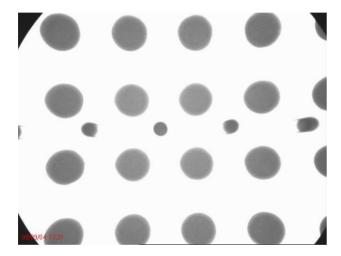
SN205 U4 SnAgCu BGA reflowed

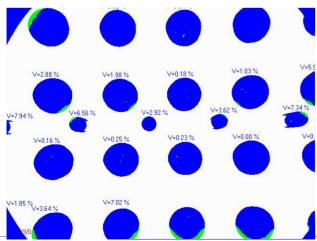
SnPb HASL PWB and Lead-Free Reflow Profile



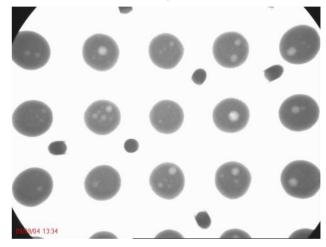
## Comparison of void percent between SnAgCu and SnPb BGAs soldered with SnAgCu solder

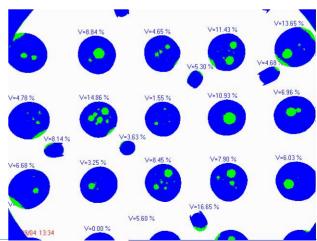
SN110 U55 LF





SN110 U56 Pb 2-15 void percent

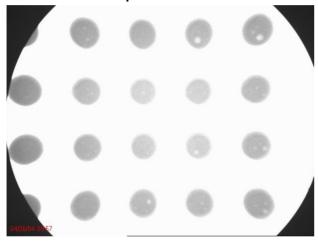


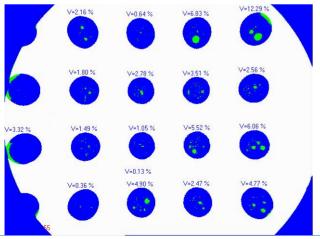




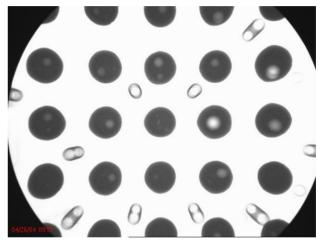
# Comparison of void percent between SnAgCu and SnPb BGAs soldered with SnAgCuBi solder

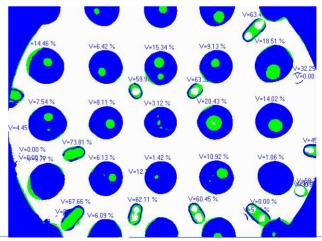
SN127 U4 SnAgCu 0.4-12 void percent





SN127 U44 SnPb 1-20 void percent

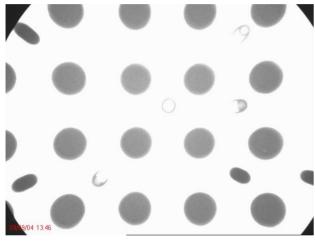


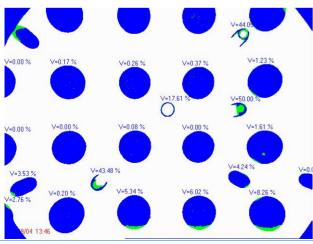




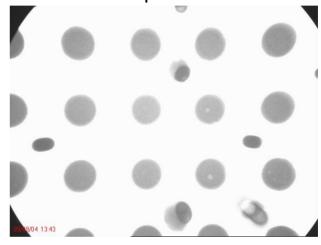
# Comparison of SnAgCu BGAs replaced on SnAgCu and SnAgCuBi Rework Assemblies

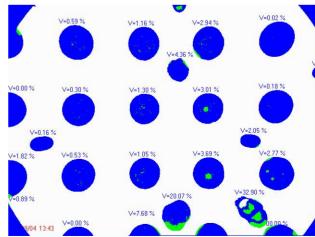
SN205 U4 reworked





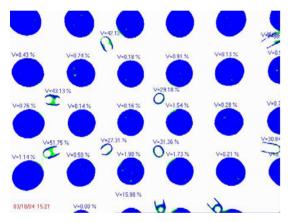
SN177 U4 reworked 0-3.69 void percent



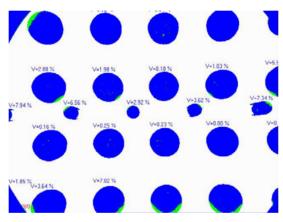




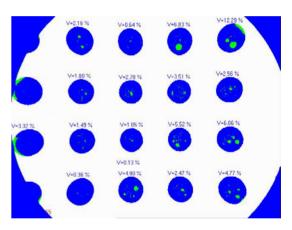
### **BGA** and Solder Comparison



SnPb with SnPb



SN110 U55 SnAgCu with SnAgCu



SN127 U4 SnAgCu with SnAgCuBi 0.36-12.29 void percent



**Surface Insulation Resistance and Electrochemical Migration Resistance** 



# **Surface Insulation Resistance and Electrochemical Migration Resistance Test Vehicles**

#### SIR

- 46 IPC-B-24 boards (SIR)
- IPC-TM-650 Method 2.6.3.3
  - 6 boards with SnAgCu reflow solder alloy and flux
  - 6 boards with SnAgCuBi reflow solder alloy and flux
  - 6 boards with SnPb reflow solder alloy and flux
  - 6 boards with SnCu wave solder alloy and flux
  - 6 boards with SnAgCu wave solder alloy and flux
  - 6 boards with SnPb wave solder alloy and flux
  - 5 boards with bare copper finish, no solder paste, only processed through cleaning procedures
  - 5 Boards with bare copper finish, no solder paste, passed through reflow and wave solder machines then cleaned

#### **EMR**

- 46 IPC-B-25A boards "D-comb pattern"
- IPC-TM-650 Method 2.6.14.1



### **Lessons Learned**



#### **Lessons Learned**

- Components are critical!
  - XRF was used to verify the surface finish of components.
    - Incorrect surface finish (mix lot) DIPs from vendor
  - Lead-free components have different moisture sensitivity ratings.
  - Logistics: Tight control of parts was required, i.e. SnAgCu Manufactured boards required a combination of tin-lead and lead-free surface finish BGAs, TSOPs, and CLCCs (only SnAgCu lead finish).
  - Because components are not marked for lead-free solder, some components were marked to differentiate between surface finish.



#### **Lessons Learned Continued**

- Solder paste printing process does not require changes when using lead-free solder.
- Component placement process does not require changes for lead-free solder.
- Reflow as expected is the major process difference.
  - Lead-free solder's full liquidus temperature is approximately 38 degrees higher than SnPb; but the components and board thermal properties have not changed.
  - The decreased process window made thermal profiling a challenge.
    - High temperature insulation thermocouples will be necessary for future work.
  - The conveyor speed was slowed down and zone temperatures increased by 20-60°C depending on oven zone.
  - Visual examination in some cases is not a good indicator whether the reflow has been accomplished; have to rely on temperature and time.
    - Lead-free solder joints have a grainy appearance, some are not as shiny, the foot of the lead on surface mount components are more visible, and they don't wet out like SnPb.



#### **Lessons Learned Continued**

- Wave soldering with lead-free solders was also challenging.
  - Solder balls were visible every where.
  - Flux material is very critical
    - flux nozzle and fluxing parameters were changed to improve the flux function
- Rework using lead-free solder also required profile changes because of the higher temperatures required.
  - A new lead-free program (template) was required.
  - Assemblies were baked before rework.
  - Extra caution was required during thermal profiling because of the maximum temperature the components can withstand (260°C).
  - Continuity test, X-ray, and ERSA were performed on each BGA after rework.
    - It may take years before confidence level is developed
  - Site cleaning was not as easy due to the higher temperatures.



#### **Lessons Learned Continued**

- Hand soldering is similar to SnPb after practice (learning curve).
  - higher temperature (700°C) tips are required
  - flux is required especially if the solder wire doesn't contain any
  - some pads were lifted due to the higher tip temperature and because the leadfree solders do not flow as well as SnPb.
- Smaller (0.37"X 0.37") polyimide labels did not withstand LF wave soldering.
- Cleaning:
  - Due to higher temperatures used, assemblies that were reworked required additional cleaning to remove flux under BGAs prior to endoscopic inspection.
- Quality Inspection:
  - The solder joint appearance varied from baseline SnPb due to the different wetting characteristics.
  - Additional training is required and our acceptability documents must be revised.
  - Visual aids would be helpful (acceptability pictures).



### **Final Comments**

### BAE SYSTEMS

	Test	Performed By
Vibration	MIL-STD-810F, METHOD 514.5, PROCEDURE I	Boeing-Seattle
Thermal Shock	MIL-STD-810F, METHOD 503.3, PROCEDURE I	Boeing-Seattle
Thermal Cycling -55°C to +125°C	IPC-SM-785	Rockwell Collins
Thermal Cycling -20°C to +80°C	IPC-SM-785	Boeing-Seattle
Mechanical Shock Pathfinder	MIL-STD-810F, METHOD 516.5, PROCEDURE I	ACI/ BAE Systems Lansdale
Mechanical Shock Test Set I	MIL-STD-810F, METHOD 516.5, PROCEDURE I	ACI/ BAE Systems Lansdale
Mechanical Shock Test Set II	MIL-STD-810F, METHOD 516.5, PROCEDURE I	ACI/ BAE Systems Lansdale
Combined Environments Test	MIL-STD-810F, METHOD 520.2, PROCEDURE I	Raytheon
Salt Fog	MIL-STD-810F, METHOD 509.4	ACI
Humidity	MIL-STD-810F, METHOD 507.4	ACI
SIR	IPC-TM-650, METHOD 2.6.3.3	Boeing-Anaheim
EMR	IPC-TM-650, METHOD 2.6.14.1	Boeing-Anaheim
Characterization		Rockwell Collins 48



#### **Acknowledgements**

The following JG-PP/JCAA companies provided technical support and/or materials that made this effort possible:

- ACI Pb-free skill training for hand soldering
- BAE Systems Irving factory time and labor expenses
- Boeing-Seattle technical support
- Florida CirTech, Inc. materials
- Global Stencil stencil services
- Heraeus materials
- Kyzen board cleaning after Pb-free wave solder
- MSL- translation of design data from Zuken Redac to GENCAD (Version 1.3).
- Rockwell-Collins provided board design, procurement of components and bare boards
- Senju Solder materials
- Vitronics-Soltec wave solder machine for Pb-free portion of assembly



# **Group Picture**





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# **Back Up Information**



### **DEK 288 Solder Paste Screen Printer**





### **Component Placement:**



FUJI CP IV used for placement of capacitors and resistors.



FUJI IP3 used for fine pitch, BGAs, and other parts.





# **Solder Reflow: ABW Systems TSC-1210**





# Cleaning: Corpane Semi Aqueous Cleaner

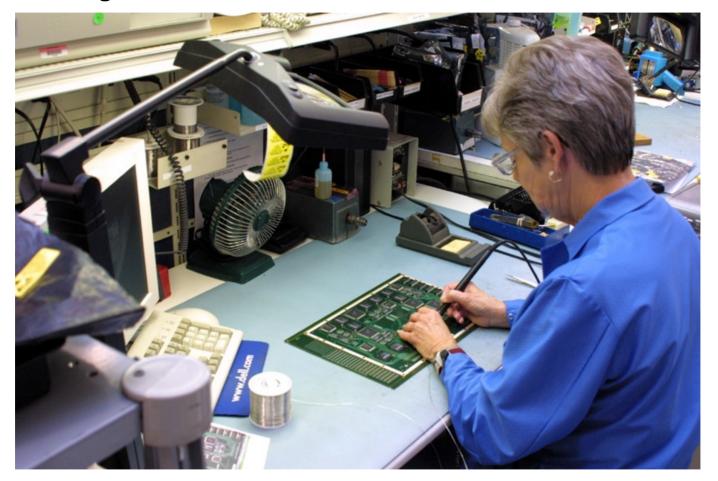




### **Evaluation- X-Ray: Nicolet Imaging Systems 1410Hb**

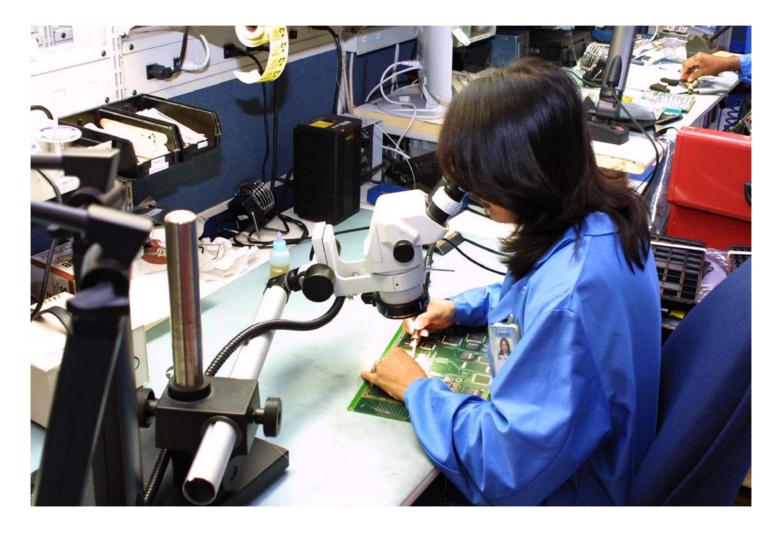


# **Hand Soldering**





# **Rework (Removal and Replacement)**





# **Wave Soldering: Delta-Max Machine**





### Wave Soldering @ Vitronics-Soltec: Delta-Wave Machine





# **BGA** removal and replacement: AIR-VAC DRS24C



